LA-UR 99-471

Approved for public release; distribution is unlimited

The TRANSIMS Approach to Emissions Estimation

M.D. Williams, G.Thayer, M.J. Barth, L.L. Smith

LA-UR 99-471

Approved for public release; distribution is unlimited

The TRANSIMS Approach to Emissions Estimation

M.D. Williams, G.Thayer, M.J. Barth, L.L. Smith

THE TRANSIMS APPROACH TO EMISSIONS ESTIMATION

99-471

Michael D. Williams

Technology and Safety Assessment Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Gary Thayer

Technology and Safety Assessment Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Matthew J. Barth

College of Engineering-Center for Environmental Research and Technology, University of California at Riverside, Riverside, California 92521-0434

LaRon Smith

Technology and Safety Assessment Division, Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

Transportation systems play a significant role in urban air quality, energy consumption and carbon-dioxide emissions. Recently, it has been found that current systems for estimating emissions of pollutants from transportation devices lead to significant inaccuracies. Most of the existing emission modules use very aggregate representations of traveler behavior and attempt to estimate emissions on typical driving cycles. However, recent data suggests that typical driving cycles produce relatively low emissions with most emissions coming from off-cycle driving, cold-starts, malfunctioning vehicles, and evaporative emissions.

TRANSIMS is a simulation system for the analysis of transportation options in metropolitan areas. It's major functional components are: (1) a population disaggregation module, (2) a travel planning module, (3) a regional microsimulation module, and (4) an environmental module. In addition to the major functional components, it includes a strong underpining of simulation science and an analyst's tool box. The purpose of the environmental module is to translate traveler behavior into consequent air quality. The environmental module uses information from the TRANSIMS planner and the microsimulation and it supports the analyst's toolbox. The TRANSIMS system holds the promise of a more complete description of the role of heterogeneity in transportation in emission estimation.

The TRANSIMS micro-simulation produces second-by-second vehicle positions defined by 7.5 meter cell locations. A continuous fit is used to produce fine-grained velocities for each 30 meter

segment of a link. The distribution of accelerations for each speed bin is estimated based on the standard deviation of speeds in the segment or the gradient of the average cube of the velocity. The model is calibrated with the use of measured speeds and accelerations for a uncongested freeway, a moderately congested freeway and a fast arterial. The speeds and accelerations are used with a new modal emissions model developed by University of California at Riverside and University of Michigan investigators. The new modal emissions model was developed after extensive testing of over 300 light-duty vehicles chosen to represent the major emission classes currently on the road. Comparisons are made for five levels of congestion on freeways and two levels of congestion on arterials.

OVERVIEW

Transportation activities contribute to excessive ozone, carbon-monoxide, and respirable particulate matter concentrations in urban areas. The air quality community has developed a number of estimation tools to address these problems. Emissions typically have been estimated by assuming that people use driving patterns similar to those over which the emissions of vehicles have been tested. With these formulations, estimates of vehicle miles traveled and average speeds can be used to estimate emissions. This basic formulation has been supplemented by corrections for cold starts, evaporation from fuel tanks, and high(super)-emitting vehicles. Recently, it has been found that current systems for estimating emissions of pollutants from transportation devices lead to significant inaccuracies (Oliver et al; 1993). One possible contributor to the inaccuracies results from deviations from the standard driving cycles that produce dramatically increased emissions (Kelly and Groblicki, 1993). When these inaccuracies are coupled to air quality models and limited meteorological data, it is difficult to tell whether the most appropriate path is being taken to achieve air quality goals (National Research Council, 1991).

The TRansportation ANalysis and SIMulation System (TRANSIMS) is being developed to address this problem as well as many other transportation analysis challenges. TRANSIMS is one part of the multi-track Travel Model Improvement Program sponsored by the U. S. Department of Transportation, the Environmental Protection Agency, and Department of Energy. Los Alamos National Laboratory is leading this major effort to develop new, integrated transportation and air quality forecasting procedures necessary to satisfy the Intermodal Surface Transportation Efficiency Act and the Clean Air Act and its amendments.

TRANSIMS is a set of integrated analytical and simulation models and supporting data bases. The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. TRANSIMS predicts trips for individual households, residents and vehicles rather than for zonal aggregations of households. TRANSIMS also predicts the movement of individual freight loads. A regional microsimulation executes the generated trips on the transportation network, modeling the individual vehicle interactions and predicting the transportation system performance.

The purpose of the TRANSIMS environmental module is to translate traveler behavior into consequent air quality (concentrations of ozone, NOx, hydrocarbons, carbon monoxide, and particulate matter), energy consumption, and carbon dioxide emissions. There are four major tasks required to translate traveler behavior into environmental consequences: (1) estimate the emissions, (2) describe the atmospheric conditions into which the contaminants are emitted, (3) describe the local transport and dispersion, and (4) describe the chemical reactions that occur during transport and dispersion of the contaminants.

The choice of components in the TRANSIMS approach is driven by the goal of representing those details that may influence the answer of the question being asked. In the context of travel the focus is on the individual traveler. Models3 (Novak, et al; 1995) will be used to translate emissions into concentrations of pollutants.

METHODOLOGY

TRANSIMS integrates advances in system science, algorithms, simulations, display techniques, databases, computer tools, and computer technology. It proceeds through several steps to create a virtual metropolitan region with a comprehensive representation of the region's individuals, their activities, and their interactions with each other and with the transportation infrastructure. A high level depiction of these steps is shown in Figure 1.

Using census data, TRANSIMS generates a synthetic population of households and individuals with the same demographic distribution as the region's actual population and locates the households and businesses along the region's streets (Baggerly, et al; 1998). With data about people's activities and the trips they make to carry out those activities, it then builds a model of household and individual activity demand that includes activity time and location.

An Intermodal Route Planner uses information about the transportation system's link travel times and costs (including transit systems) to plan an individual's travel modes and routes for the day. These travel plans then are executed in a simulation of the movement of individuals across the transportation network, including their use of vehicles such as cars or buses, on a second-by-second basis. This virtual world of travelers mimics the traveling and driving behavior of real people in the region. The interactions of individual vehicles produce realistic traffic dynamics from which analysts can judge the overall performance of the transportation system and can estimate vehicle emissions. The Emissions module converts the Microsimulation vehicle data (location, velocity, acceleration, etc.) to estimated vehicle emissions that are input to a regional air quality model such as EPA's Models3.

The functionality of TRANSIMS however is more than just using activity demand to produce trip plans and then using trip plans to generate executed travel. A key element comes from the feedback of information from the executed travel in the microsimulation to the route planner and the activity demand and the executing the travel again. The interaction of information from the microsimulation back to the route planner can be used in two ways. First, iteration "relaxes" the model inherent to the simulation into a refined simulation solution of all travelers. In this way activities and trip plans for the synthetic travelers are adapted in response to encountered simulated travel difficulties or favorable experiences. Second, it models information movement from the subsystems to certain travelers according to specific ITS strategies.

The arrows in Figure 1 indicate the information flow. The solid arrows follow the iteration process in which modes, routes, and the activity departure times for the synthetic travelers are adjusted to improve travel performance.

The microsimulation executes the trip plans, following each traveler second-by-second through the network including transfers between travel modes. The microsimulation uses a cellular-automata approach in which each lane is broken into 7.5 meter cells, and vehicles are moved an integer number of cells in each second. Vehicles speed up, change lanes, or turn across on-coming lanes depending upon the gap available. They also randomly accelerate one-gap less than they otherwise would. The microsimulation provides an accurate description of major traffic features (Nagel et al; 1998), but it does not accurately describe the distribution of accelerations due to the quantum step nature of the CA approach. A major focus of this paper, as described in the section on emission modules, is the development and testing of techniques to produce appropriate speeds and accelerations from the microsimulation output.

The initial set of trip plans when executed by the microsimulation produces interactions among the travelers on the transportation network. The interactions may lead to unrealistic congestion delays on the freeways, arterials, local streets, transit queues, etc. An output subsystem accumulates link summary output from this simulated "real world." The accumulated information is generally average link travel times during fixed time intervals, say 15-minutes, but other traveler costs (e.g., transit fares, tolls, travel time variability) may be included as well. Using this information as an updated estimate of the network state, the intermodal route planner then finds possible new modes, routes, and departure times for selected synthetic travelers (Nagel et al: 1998b).

A subset of the travelers are chosen to find better travel times, lower financial costs, or lower travel-time variabilities when traveling to their destinations. The plans for all travelers, selected and not selected, are executed again in the microsimulation. Even though the travel plans have not changed for the unselected travelers, their interactions with selected travelers now differ and the executed travel for both sets of travelers changes. Continuing this iteration process, travel through the transportation system is adjusted until each individual executes, in some sense, his optimal trip for carrying out his activities given that all the other travelers are attempting to do the same. In this manner, modes, routes, and departure times are adjusted to avoid congested areas during peak periods.

This iteration process continues until the system relaxes to a stationary state. Note that stationary state for this system does not mean that everything remains the same between iterations. Rather relative invariability in selected output variables or measures of effectiveness determine when the system has relaxed to a "steady state." Such measures also establish whether two states of the transportation system are close to one another or possibly equal.

EMISSION MODULES

The primary output of the transportation microsimulation module is summarized cellular-automata (CA) data. The CA describes the vehicle position in units of cells, velocity in units of cells per second, and the acceleration in units of cells per second per second. A typical cell size is 7.5 meters so that the resulting motion, in 16 mph increments, is too coarse to be used directly as input to the emissions module. We are developing an approach to produce realistic, smooth vehicle trajectories that can be used in the emissions module.

One of the major challenges of appropriately modeling emissions is to account for the effects of different power-demands by different drivers. With light-duty vehicles, there are a wide range of accelerations available to the driver. The driver that favors harder accelerations may put the vehicle into an "enrichment" mode. During enrichment conditions, the vehicle's fuel controls switch to a fuel-rich situation that produces high emissions from the engine, and, since the catalyst is starved for oxygen it does not reduce the emissions significantly. This fuel-control logic protects the catalyst from getting too hot, but it enormously increases the emissions of the vehicle.

There are two options to deal with this challenge: (1) construct a fast, accurate microsimulation that describes traffic and power demands in great detail, or (2) supplement a fast microsimulation that describes traffic properly with empirical information on power demands. One of the major difficulties with option 1 is finding adequate information describing the range of driving behavior in specific circumstances. There is much more information on traffic than there is on individual driving speeds and accelerations. For this reason we have chosen option 2. We have developed a microsimulation that describes traffic accurately and efficiently. From the microsimulation we know the context in which driving occurs, and we have developed a system, the LDV Aggregate Dynamics module, to put empirical information into the context. There are three major sub- modules to the emission module: (1) evaporative module, (2) light-duty tailpipe module, and (3) a heavy duty tailpipe module. The evaporative module treats emissions associated with resting losses, running losses, hot soaks, and diurnal pressure changes. It deals with both normally operating vehicles and with vehicles with significant leaks in the fuel system.

The light-duty tailpipe module treats tailpipe emissions from cars, light-duty trucks, and sport-utility vehicles. Important aspects include: (1) malfunctioning vehicles, (2) emissions from starts, (3) emissions with variable soak-times, (4) emissions from off-cycle conditions which render the pollution controls inefficient and (5) normal driving. With regard to off-cycle conditions, very high emissions occur at high power demands. The phrase off-cycle refers to conditions outside those that occur in the Federal Test Procedure (FTP, 1989). Emissions in this context are very sensitive to the precise acceleration that occurs at a specific speed.

The heavy-duty tailpipe module treats tailpipe emissions from trucks and buses. While truck emissions are not as sensitive to demanded power levels as are light-duty vehicles, their emissions are sensitive to the load carried by the vehicle. The development of heavy-duty tailpipe module is currently incomplete and its performance is not discussed in this paper.

The information flow of the environmental module is summarized in Figure 2. The module requires information on the fleet composition developed from the synthetic population module, information on I & M test results, truck loads, and traffic patterns. The traffic patterns are produced by the micro-simulation.

The output of the system is aggregate emissions on the 30 meter segments for each 15 minute period simulated. Fuel economy and CO2 emissions are also estimated. The emission inventory is designed to be used with EPA's MODELS -3 to produce 3-dimensional hourly gridded emissions over the metropolitan area.

Work on the evaporative model is in progress; suffice to say the evaporative module uses the evaporative modeling approaches in MOBILE 5 for running losses and proposed MOBILE 6 formulation for hot soaks, resting losses, and diurnal emissions. The heavy-duty vehicle module is also under development. It will be based on a heavy-duty modal model under development by West Virginia University investigators. The focus of this paper is on the development of the light-duty vehicle tailpipe module. Furthermore, the treatment of variable soak-time starts and some other aspects of transient vehicle behavior have yet to be completed and will not be discussed in this paper.

The light-duty tailpipe model treats emissions from off-cycle driving, malfunctioning vehicles, normal driving, idling, and vehicles with cold engines and /or catalysts. There are three major sets of information which must be developed: (1) what is the fleet composition, (2) what is the fleet status, and (3) what is the fleet doing. Once these questions are answered the LDV tailpipe module can produce the emissions.

Fleet composition is developed from vehicle registration data, inspection and maintenance testing, or data developed for EPA’s MOBILE model runs. Barth and his colleagues (Barth et. al; 1997) have developed techniques to take registration data and produce vehicle populations in each of 24 categories required for their model. The categories include factors such as low or high engine to weight ratio, car or truck, mileage above or below 50,000, type of catalyst (2-way or 3-way), carbureted or fuel-injected, and high-emitting or normal emitting. In areas where there is a sophisticated inspection and maintenance program that tests vehicles on a dynamometer, improved estimates of the proportion of high-emitting vehicles can be made. With this approach, the role of inspection and maintenance is to transform some of the malfunctioning vehicles into normally operating vehicles.

Fleet status is developed from the pattern of usage of the vehicles traversing a given link. The micro-simulation keeps track of when and where the vehicles have been operating.This can be used to determine how many vehicles on this link are operating under cold-start conditions. Cold engines burn fuel-rich until the engine has burned enough fuel to bring the engine temperature up to normal. Similarly, the catalyst efficiency is reduced until enough fuel has been burned to bring the catalyst up to normal operating ranges. Within a given vehicle category, the principal determinants of fuel consumption are speed and power demanded. Fuel consumption is slightly increased during cold-engine operation for a short time. The fleet status elements of TRANSIMS are still under development.

There is a relationship between the continuous power output, velocity of the vehicle, the vehicle type, and emissions. The relationships are complex and non-linear and they vary by the type of vehicle. The formulae that describe these relationships are invariant between cities, although the fleet composition may vary between cities. The environmental module uses the relationships to develop the fleet emissions for each 30 meter segment of each 15 minute period.

The Synthetic Population Post-Processor and the Plans and Inspection and Maintenance Post-Processor provide the fleet composition. The microsimulation provides the number of vehicles in each 7.5 meter per second speed cell for each 30 meter segment. These data are used by the light-duty vehicle dynamics module to represent the fleet in sufficient detail to provide accurate estimates of the fleet emissions. Because of the non-linear character of the relationships between emissions and combinations of speed and power, emissions are calculated for vehicles representing each two mile per hour increment in speed. Furthermore for each speed bin there are calculations for vehicles representing 25 different levels of power (or acceleration). The module computes the numbers of vehicles in each of these representative speed and power bins.

The apportionment of the number of vehicles into these power/speed bins is based on relationships developed from actual measurements of vehicle behavior under a variety of conditions. First, during EPA’s three city studies (USEPA, 1993) many vehicles were fitted with a data-logger that recorded times and speeds throughout the vehicle’s travels for a significant period. This data was examined to determine what the frequency distribution of accelerations is for a given speed. More specifically we looked for the cumulative frequency of positive accelerations. Figure 3 reports the cumulative frequency of vehicles traveling faster than one cell per second and having positive accelerations against the product of acceleration and speed.

It is evident that for higher power levels, the frequency of a given power level falls off exponentially with power. Similar plots can be made for speeds less than 1 cell per second and for decelerations. In the case of decelerations, the frequency falls off exponentially with the velocity-deceleration product. These relationships form one of the empirical underpinnings of our approach. We consider all accelerations in one of three groups: (1) hard accelerations, (2) insignificant accelerations, and (3) hard decelerations. Hard accelerations are defined by accelerations greater than those associated with the 10% point on the cumulative distribution. For example in Figure 3 the definition of high-power acceleration would be velocity-acceleration products greater than 48 mph per second squared. Similar definitions can be found for hard accelerations starting at speeds less than 1 cell per second and for hard decelerations. We estimate the number of vehicles undergoing a high-power acceleration and then choose 12 different power levels to represent different levels of aggressiveness. The power levels are chosen from the curve of Figure 3 with equal spacings in power and covering the range from a cumulative frequency of.1 to a cumulative frequency of.0045. The total population of vehicles undergoing high-power acceleration from a given speed is then distributed over the 12 power (or equivalently acceleration) levels in accordance with Figure 3. These data are used to estimate the relative proportions of vehicles having different levels of acceleration within the group of vehicles that undergo hard accelerations.

In the module the first step is to estimate the population of vehicles in each 2 mile per hour speed bin from the populations in the 7.5 meter per second speed cells for each link segment. This is done by assuming that the continuous speed distribution can be approximated with a series of line segments of the form:

$$d(\delta v) = d_0 + d_1 \delta v$$

with

$$\delta v = v - v_c$$

and v_c the speed at the cell center. The constant term d_o is the average over the cell and the slope term d_1 is determined by requirement that d be continuous across the speed cell boundaries.

We use these relationships to apportion the vehicles into 2 mph speed bins. We also use them to calculate the standard deviation of the speed in each segment along the link and estimate the average speed, average square of the speed, or the average cube of the speed in each segment. By looking at the changes in the average cube of the speed we can estimate the average power in the segment, since the power is related to the speed-acceleration product and:

$$vA = v\frac{dv\,dx}{dx\,dt} = v^2\frac{dv}{dx} = \left(\frac{1}{3}\right)\frac{dv^3}{dx}.$$

Our problem is not quite this simple because the average power is not adequate to describe the emissions because of the non-linear relationship between emissions and power. However we expect that the average power does influence the probability of a hard acceleration. We also expect that the probability of a hard acceleration is influenced by the standard deviation of speeds, because a large standard deviation of speeds implies that many vehicles are below their desired speeds and will use available opportunities to accelerate to higher speeds. In fact we found that a simple linear relation between either gradient of the average cube of the speed or the standard deviation of speed is sufficient to estimate the probability of a hard acceleration for a very wide range of driving circumstances. In practice for each segment of a link we estimate the probability of a hard acceleration associated with changes in the average cube of the speed and we estimate the probability of a hard acceleration associated with the standard deviation of speeds and choose the larger. The parameters defining the link between the probability of a hard acceleration and the change in the average speed cubed were chosen by examining the change in emissions with average power along a single fast arterial and focussing on the portion of the link adjacent to the signal at the start of the link. The parameters defining the relationship between the standard deviation of speed and the probability of a hard acceleration were chosen by comparing a fast freeway where the standard deviation of speed was minimized to a moderately congested freeway where the standard deviation of speed was maximized.

Originally, this approach was developed and tested with a modal emission model developed by University of Michigan investigators (Ross et. al, 1996). We elaborated on the basic approach by breaking the total vehicle flux into thirds and calibrating the probability of a hard acceleration by each third. Thus we would have slightly different calibration parameters of the fastest third, the intermediate third, and the slowest third. The fastest third has no contribution from the standard deviation of speeds since it is assumed that the fastest third has reached desired speeds.

We also developed an adjustment for the vehicles that are going slower 7.5 meters per second. These vehicles fall on a different cumulative distribution of power with an exponential decay of about twice that of the higher speed vehicles. To account for this difference we computed the probability of a hard acceleration and then multiplied it by the ratio of the exponent for the low speed curve to that of the higher speed curve. This approach allows us to infer realistic speeds and accelerations from the microsimulation's coarse speed groups.

We have tested this system for three levels of congestion on arterials and 7 levels of congestion on freeways (Effa and Larson, 1993) in addition to a dataset drawn for the least congested arterial set, but using only the vehicles with starting speeds less than five miles per hour.

For our current results, we are using the latest Comprehensive Modal Emission Model (CMEM) developed under National Cooperative Highway Research Program (NCHRP) Project 25-11 [Barth et al., 1997, An et al., 1997]. CMEM thus far has been developed for 23 different vehicle/technology classes of light duty vehicles. Extensive tests were carried out on over 300 vehicles chosen to represent the major types of emitters in the existing light-duty vehicle fleet. CMEM also incorporates other data to help draw associations between the tested vehicles and the fleet at large.

The model computes the tractive power by taking account engine friction losses, rolling resistance, wind resistance, changes in kinetic energy, and changes in potential energy. It also considers the power to drive accessories such as air conditioning and it estimates drivetrain efficiency. With the engine power known, it calculates the rate of fuel consumption and engine out emissions. It treats enrichment, enleanment, and stoichiometric operations as well as cold-start operation.

Once the engine-out emissions are calculated, catalyst pass fractions are used to calculate the tailpipe emissions. The approach uses a composite vehicle to represent vehicles in the same class. A regression approach was used to define the parameters required by the model. The vehicles were all tested over cycles involving very high power demands and a variety of driving patterns.

There are composite vehicles representing normal emitting cars categorized by technology, low and high power to weight ratios, and mileages above or below 50,000. The technology categories are: (1) no catalyst, (2) 2-way catalyst, (3) 3-way catalyst with carburetion, (4) 3-way catalyst with fuel injection, (5) Tier 1. Only the last two technologies are broken into mileage or power to weight ratio groupings. There are high emitting composite vehicles for technologies (3) through (5), but they are not further subdivided into power to weight ratios or mileage groupings.

There are composite vehicles representing normal-emitting trucks with model year categories: (1) pre-1979, (2) 1979 to 1983, (3) 1984 to 1987, (4) 1988 to 1993, (5) 1994 and newer. In age categories (1) through (3) there is only a single composite vehicle. For age category (4) there are categories for trucks above and trucks below 3750 pounds loaded vehicle weight, while for category (5) there is a category for trucks with loaded vehicle weights between 3751 and 5750 pounds and a category for gross vehicle weights between 6001 and 8500 pounds. There are composite vehicles representing high-emitting trucks for model years 1984 to 1987, 1988 to 1993, and 1994 and newer. In the high-emitting category, there are no breakdowns by vehicle weight.

In order to construct the test, we constructed a composite vehicle using the fleet distribution representative of the Riverside, California region. We calculated emissions for each 2 mph speed bin and each 1.5 foot per second acceleration bin using the midpoint of the speed and acceleration bin in each case. This approach does not consider the history effects on emissions that we will address later with the model developed by Barth and his colleagues (Barth, et al,1997).

With the composite vehicle emission arrays, we calculated emissions for each second of each vehicle's travel and assigned those emissions to the 7.5 meter cell that the vehicle was in at the start of the second. For each trajectory in the original dataset we calculated 4000 trajectories beginning with random offsets within the first second of travel and the first 7.5 meters of travel. We accumulated these emissions by cell and normalized the results to represent the emissions from a single typical trajectory. We report these emissions as the "trajectory-implied" emissions.

For the estimated emissions we aggregated the vehicles in the same dataset used to obtain the "trajectory-implied" emissions into 30 meter segments and 7.5 meter per second speed bins. We then fit the resulting distribution with continuous line segments in velocity and calculate the probabilities of hard accelerations and distribute those accelerations over the acceleration bins using the exponents from the cumulative distributions. With the speed bin and acceleration bin populations known, we estimated the emissions for each 30 meter segment and interpolate to get 7.5 meter cell emissions.

RESULTS

Figure 4 reports the comparison of speeds between the same two cases for three levels of congestion denoted freeway 2, freeway 4, and freeway 6. Note that for freeway 6 there is a significant increase in the average speed near the end of the plot. This is the result of slower vehicles disappearing before they reach that downstream distance, because the original trajectories were only 30 seconds long. Figure 5 reports the comparison for the NOx emissions. In this case, the emissions decrease near the end because there are fewer vehicles left in the set and the normalization was by vehicles starting the segment. Figure 5 shows that there is relatively little speed influence on NOx emissions with emissions per cell being a little higher for the lowest speed considered. Figure 6 reports the comparison for hydrocarbon emissions. The hydrocarbon emissions seem to increase as the speed decreases. None of these freeway segments were used in the original calibration for the constants that determine the probability of a hard acceleration. The NOx emissions near the start of the arterials are higher than the emissions on the freeways, while the hydrocarbon emissions follow the same pattern for the faster freeways and arterials. However the most congested freeway produces the highest hydrocarbon emissions.Table 1 summarizes the comparison for a 300 meter link.

Table 1. Comparison between Estimated andTrajectory-implied Emissions.

Data set	speed (mph)	est. speed (mph)	NOx (mg)	est. NOx (mg)	HC (mg)	est. HC (mg)	CO (gm)	est. CO (gm)
slowest arterial	27.5	27.5	520.	524.	331.	335.	3.76	4.22
medium arterial	30.8	31.1	552.	571.	334.	350.	3.86	4.74
arterial from stop	20.4	20.6	422.	421.	312.	317.	3.24	3.49
freeway 2	45.8	45.7	446.	470.	255.	265.	3.32	3.68
freeway 4	28.0	27.9	428.	440.	291.	296.	3.26	3.44
freeway 5	22.4	22.4	429.	414.	309.	308.	3.15	3.47
freeway 6	20.4	20.6	422.	421.	312.	317.	3.24	3.49

These results show that vehicle populations that are lumped into 30 meter segments and 7.5 meter- per-second speed bins can be used to produce emissions that are very similar to those obtained from individual second-by-second trajectories.

CONCLUSIONS AND FUTURE WORK

We have developed a system for converting aggregate spatial and velocity groups into distributions of speeds and accelerations appropriate for emission calculations using the TRANSIMS framework. Critical parameters for emissions calculations are: (1) the number of vehicles entering the link, (2) the gradient in speeds along the link, and (3) the standard deviation of speeds in each portion of the link. The testing of the system also provides insight into vehicle emission behavior. On a per trajectory basis the NOx emissions per unit distance are relatively insensitive to average speed, but they increase significantly with the gradient of speed and are highest as vehicles leave intersections. For hydrocarbons the emissions are high as vehicles leave intersections, but they are also high on very congested links.

We have developed methods to capture the effects of cold or warm starts, but their description is not included in this paper. We would like to address freeway on-ramp emissions and the effects of grades. We also need to develop the heavy-duty vehicle module and complete the evaporative emission module. We need to calibrate and test the module with CA data from the TRANSIMS microsimulation rather than with CA-like aggregations of measured data.

ACKNOWLEDGMENTS

This work was supported by the US Department of Transportation, the US Environmental Protection Agency, the National Cooperative Highway Research Program, and the University of California Directed Research and Development Fund. The filter program uses a quadratic programming solver developed by P. Spellucci (spellucci@mathematik.th-darmstadt.de). Myron Stein was of great help in the code development

REFERENCES

Oliver, W.R., R.J.Dickson, and L. Bruckman (1993), “Development of the SCAQS High-Resolution Emissions Inventory: Assessment of Inventory Uncertainties,” in Proceedings of an International Specialty Conference, Southern California Air Quality Study, Data Analysis, VIP-26 published by the Air & Waste Management Association, Pittsburgh, Pennsylvania,. pp 62-73.

Kelly, Nelson A. and Peter J. Groblicki (1993), “Real-World Emissions from a Modern Production Vehicle Driven in Los Angeles,” *J. Air Waste Management Assoc*. **43**, pp 1351-1357.

National Research Council (1991), “Rethinking the Ozone Problem in Urban and Regional Air Pollution,” National Academy Press, Washington, D.C., p 6.

Novak,J. H., R. L. Dennis, D. W. Byun, J. E. Pleim, K. J. Galluppi, C. J. Coats, S. Chall, and M. A. Vouk, (1995), “EPA Third-Generation Air Quality Modeling System: Volume 1 Concept”, US Environmental Protection Agency, Research Triangle Park, NC 27711, EPA600/R95/082

Baggerly, Keith, Richard Beckman, Michael McKay, Douglass Roberts, (1998), “TRANSIMS Synthetic Population System User Guide”, Los Alamos National Laboratory, Los Alamos, New Mexico, LA-UR-98-9693.

Nagel, Kai, Dietrich E. Wolf, Peter Wagner, and Patrice Simon (1998), “Two-Lane Traffic Rules for Cellular Automata: A Systematic Approach,” *Physical Review E*, **58**, pp 1425-1437.

Nagel, Kai, Marcus Rickert, and Patrice M. Simon,(1998b), “The Dynamics of Iterated Transportation Simulations”, Los Alamos National Laboratory, Los Alamos, New Mexico, LA-UR-98-2168.

FTP.(1989). Code of Federal Regulations. Title 40. Parts 86-99 (portion of CFR which contains the Federal Test Procedure), Office of the Federal Register.

Barth, M., T. Younglove, T. Wenzel, G.Scora, F. An, M. Ross, and J. Norbeck (1997), “Analysis of Modal Emissions for a Diverse in-use Vehicle Fleet.” *Transportation Research Record*, **1587,** Transportation Research Board, National Academy of Science, pp. 73-84.

USEPA (1993), “Federal Test Procedure Review Project: Preliminary Technical Report,” EPA 420-R-93-007, Office of Air and Radiation, Washington, DC.

Ross, Marc, Rob Goodwin, Rick Watkins, Michael Q. Wang, and Tom Wenzel (1996), “Real-World Emissions from Model Year 1993, 2000, and 2010 Passenger Cars,” Lawrence Berkeley National Laboratory, LBL-3977, Berkeley, California.

Effa, Robert C. and Lawrence C. Larson (1993), “Development of Real-World Driving Cycles for Estimating Facility-Specific Emissions from Light-Duty Vehicles,” California Environmental Protection Agency - Air Resources Board - presented at the Air and Waste Management Association Specialty Conference on Emission Inventory, Pasadena, California.

An F. and Marc Ross (1993), “A Model of Fuel Economy and Driving Patterns, “SAE 930328.

F. An, M. Barth, J. Norbeck, and M. Ross, "The Development of a Comprehensive Modal Emissions Model: Operating Under Hot-Stabilized Conditions," *Transportation Research Record* **1587**, TRB, National Research Council, Washington, D. C., 1997, pp. 52-62.

Wenzel, T. and M. Ross. (1996). Emissions from Modern Passenger Cars with Malfunctioning Emission Controls. SAE Technical Paper #960067.

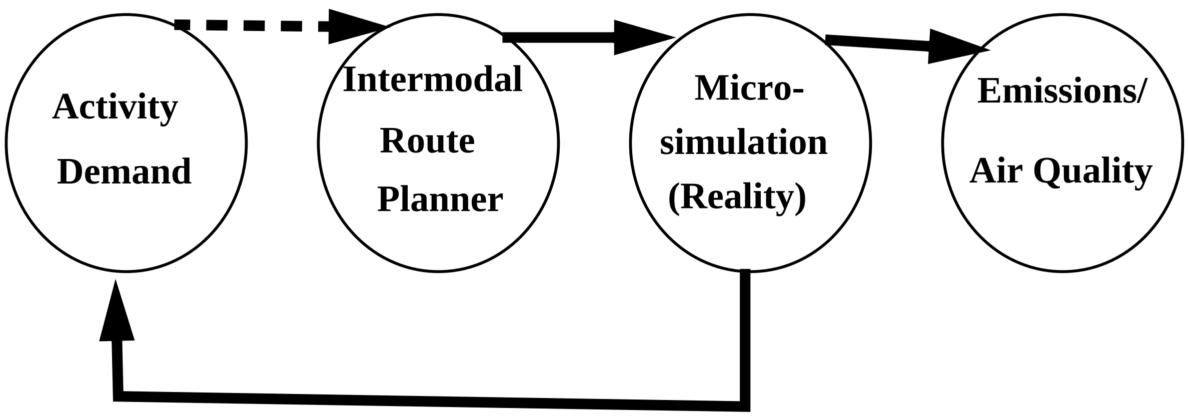

Figure 1. Major Modules in the TRANSIMS Framework

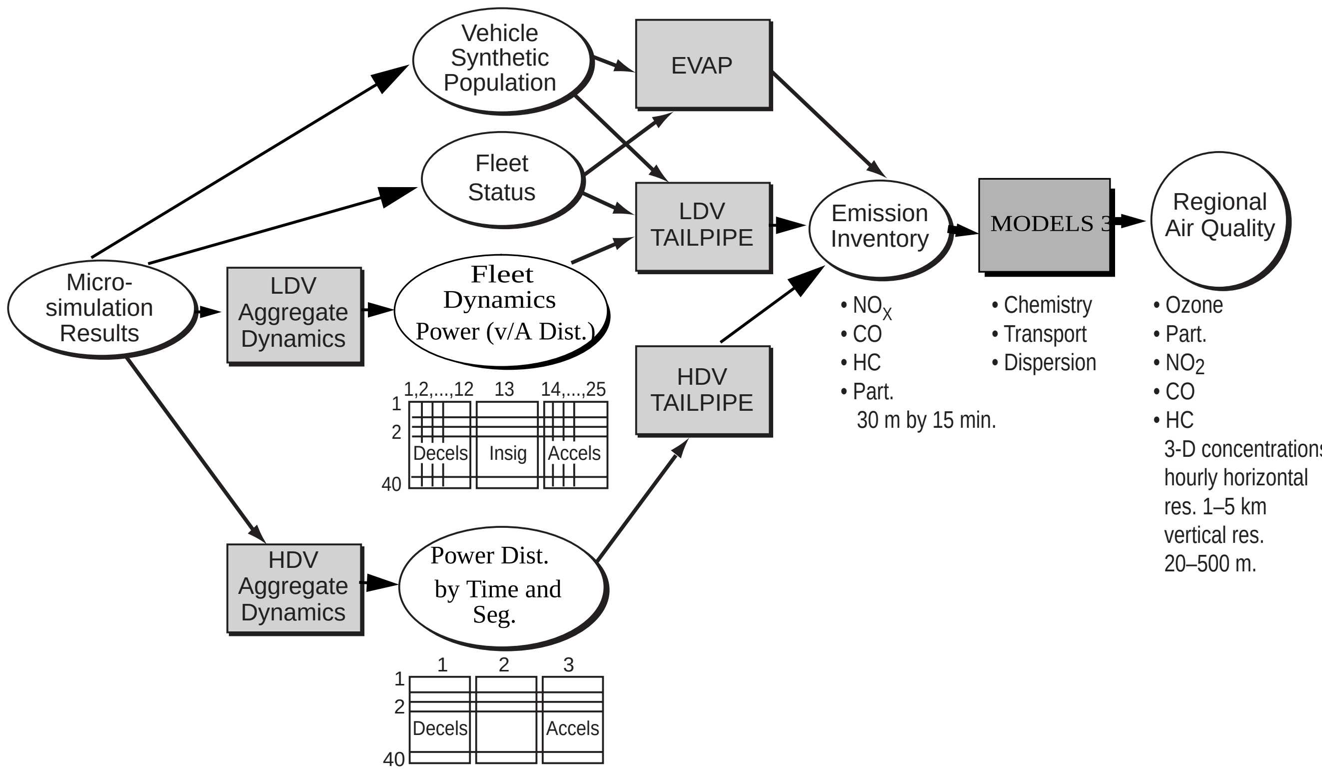

Figure 2. TRANSIMS Emission Module Information Flow.

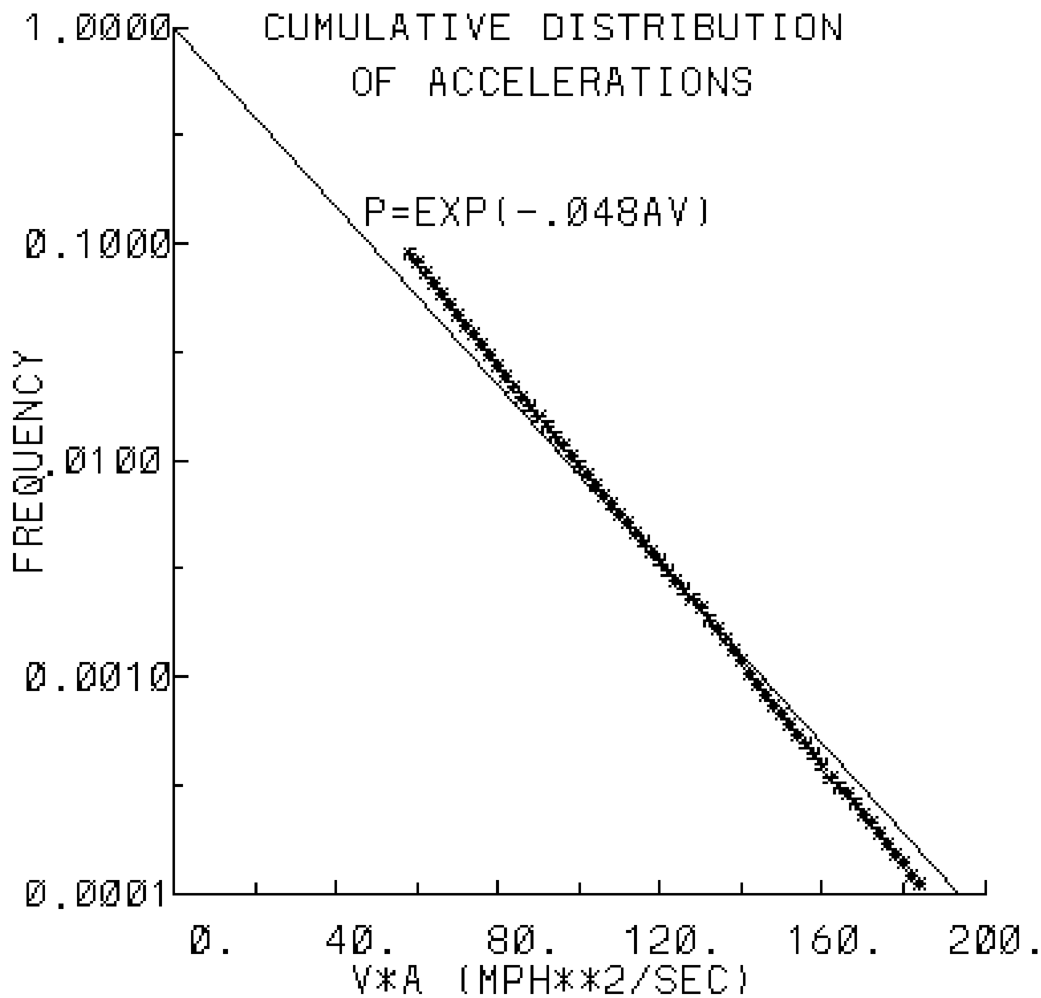

Figure 3. Cumulative Distribution of Accelerations for vehicles traveling more than 7.5 meters per second.

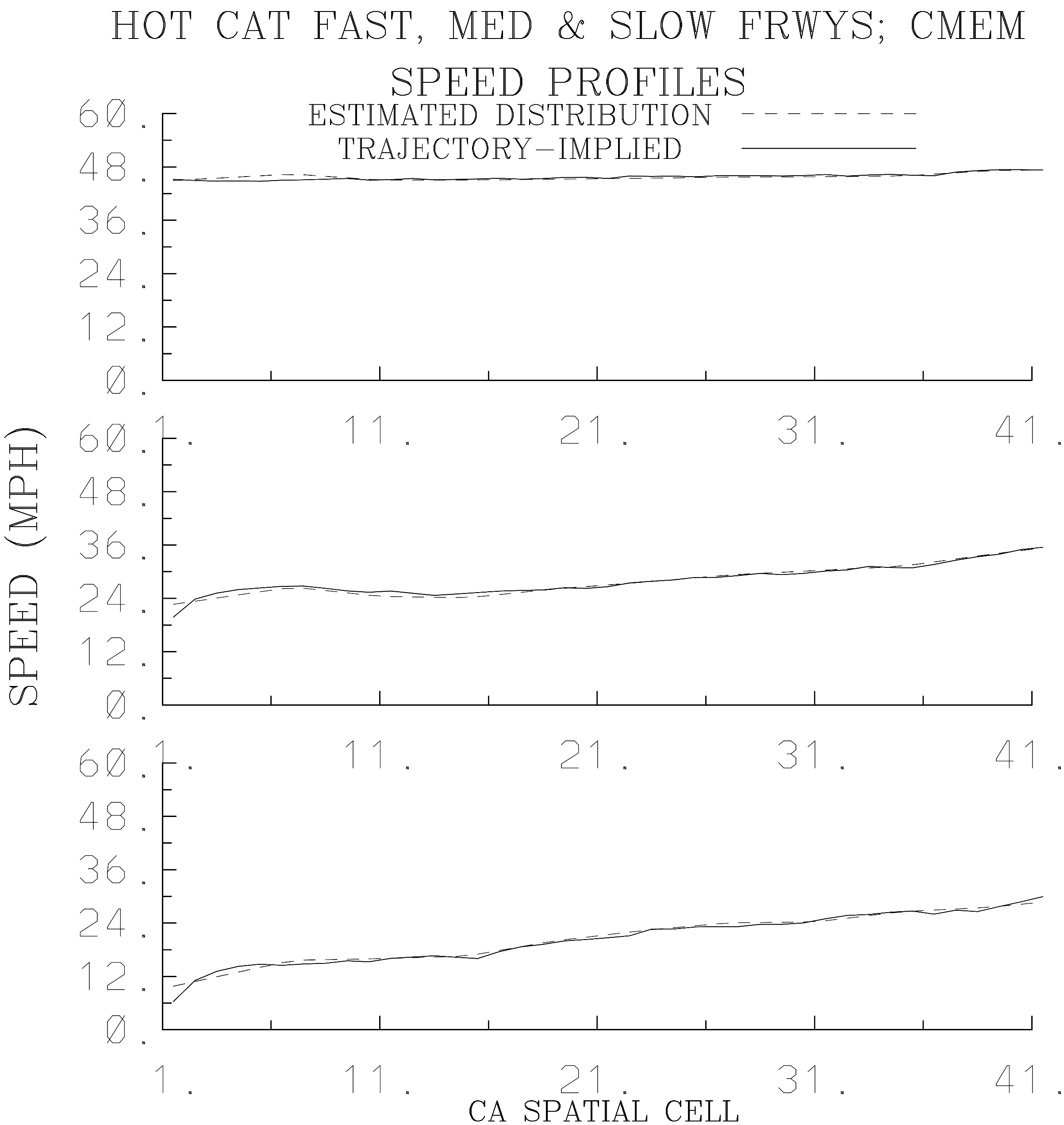

Figure 4. Comparison of estimated and trajectory-implied speeds for freeway 2 (top), freeway 4 (middle), and freeway 6 (bottom).

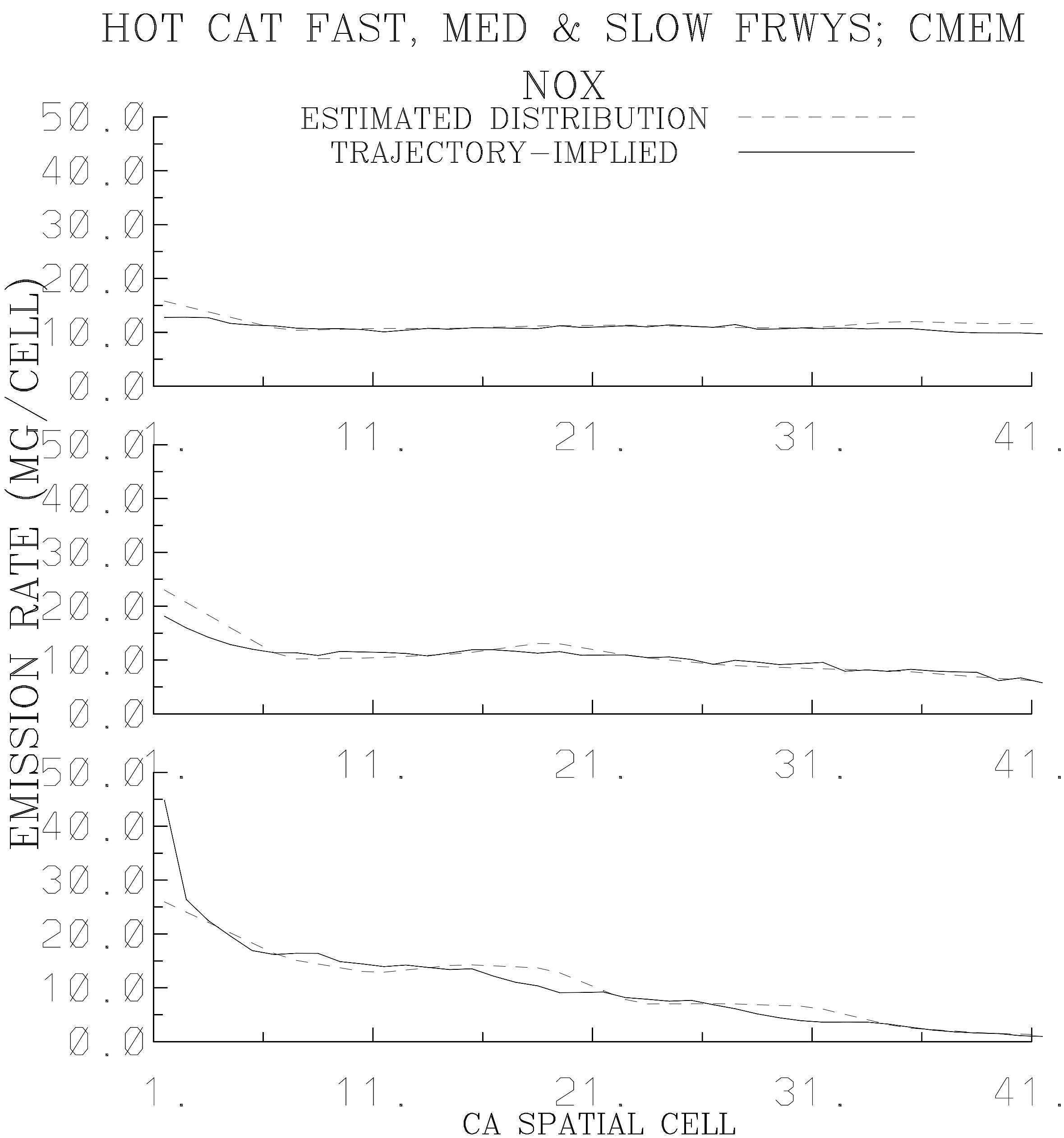

Figure 5. Comparison of estimated and trajectory-implied NOx emissions for freeway 2 (top), freeway 4 (middle), and freeway 6 (bottom).

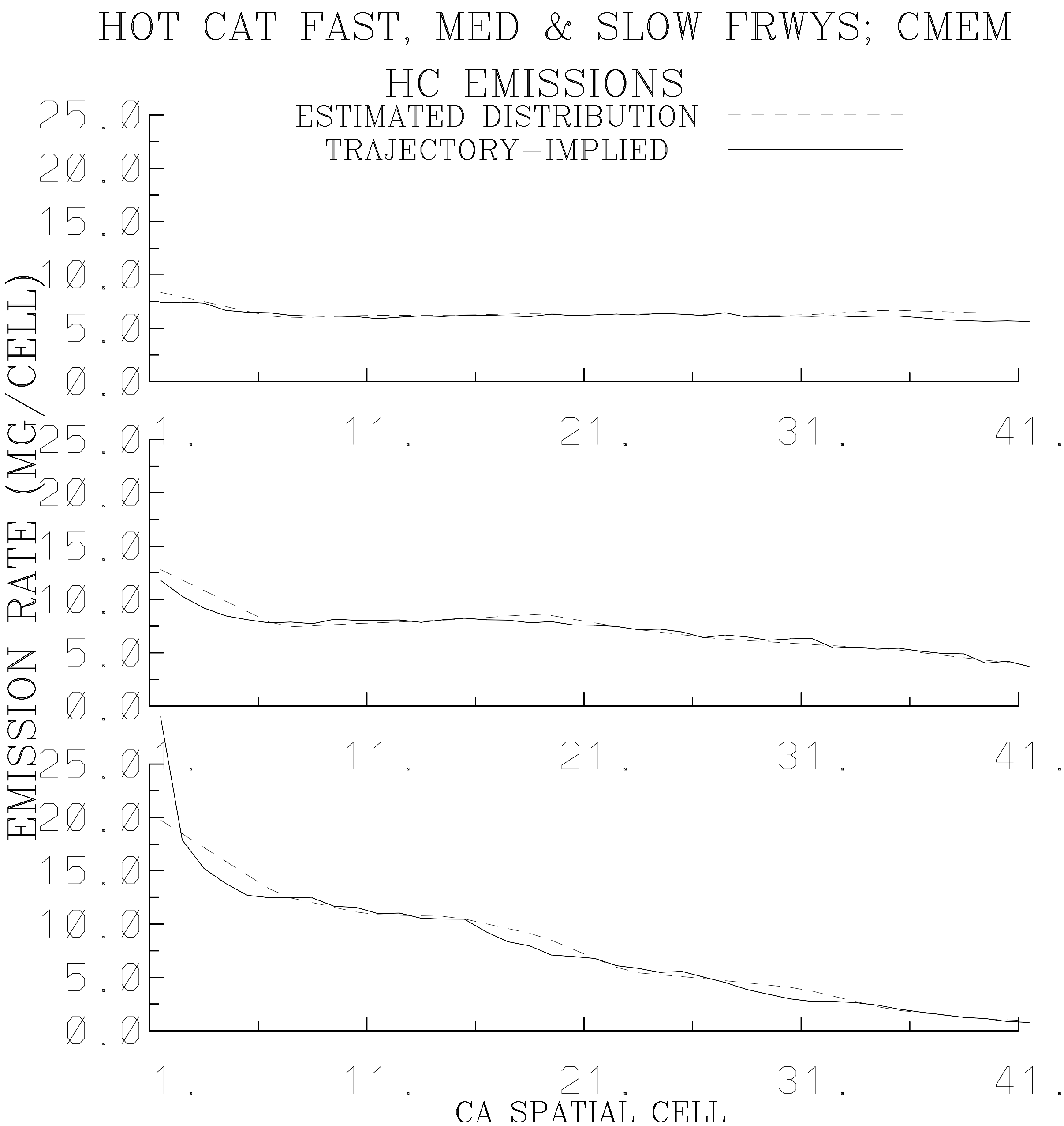

Figure 6. Comparison of estimated and trajectory-implied hydrocarbon emissions for freeway 2 (top), freeway 4 (middle), and freeway 6 (bottom).

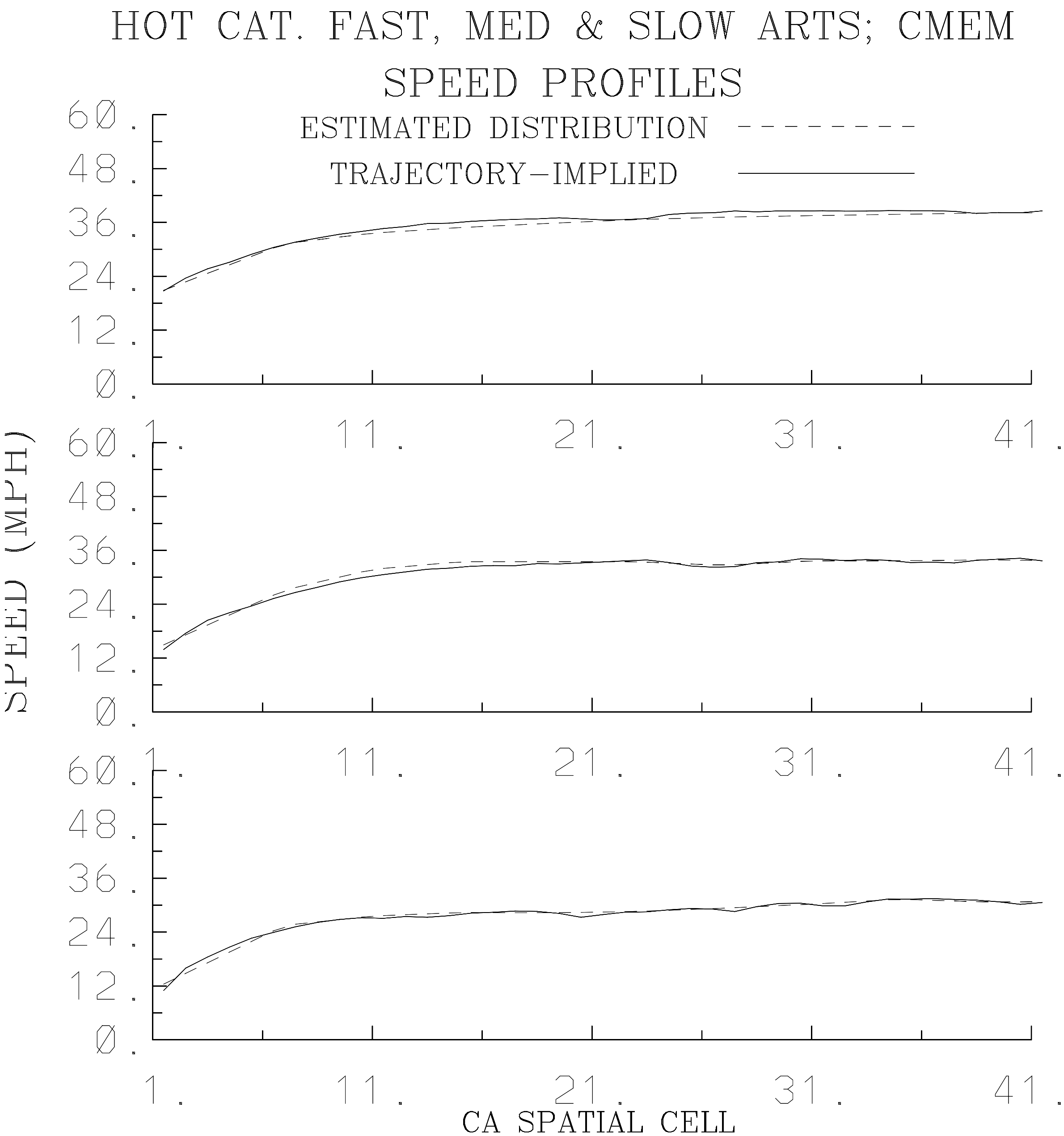

Figure 7. Comparison of estimated and trajectory-implied speeds for a fast arterial (top), a medium arterial (middle), and a slow arterial (bottom).

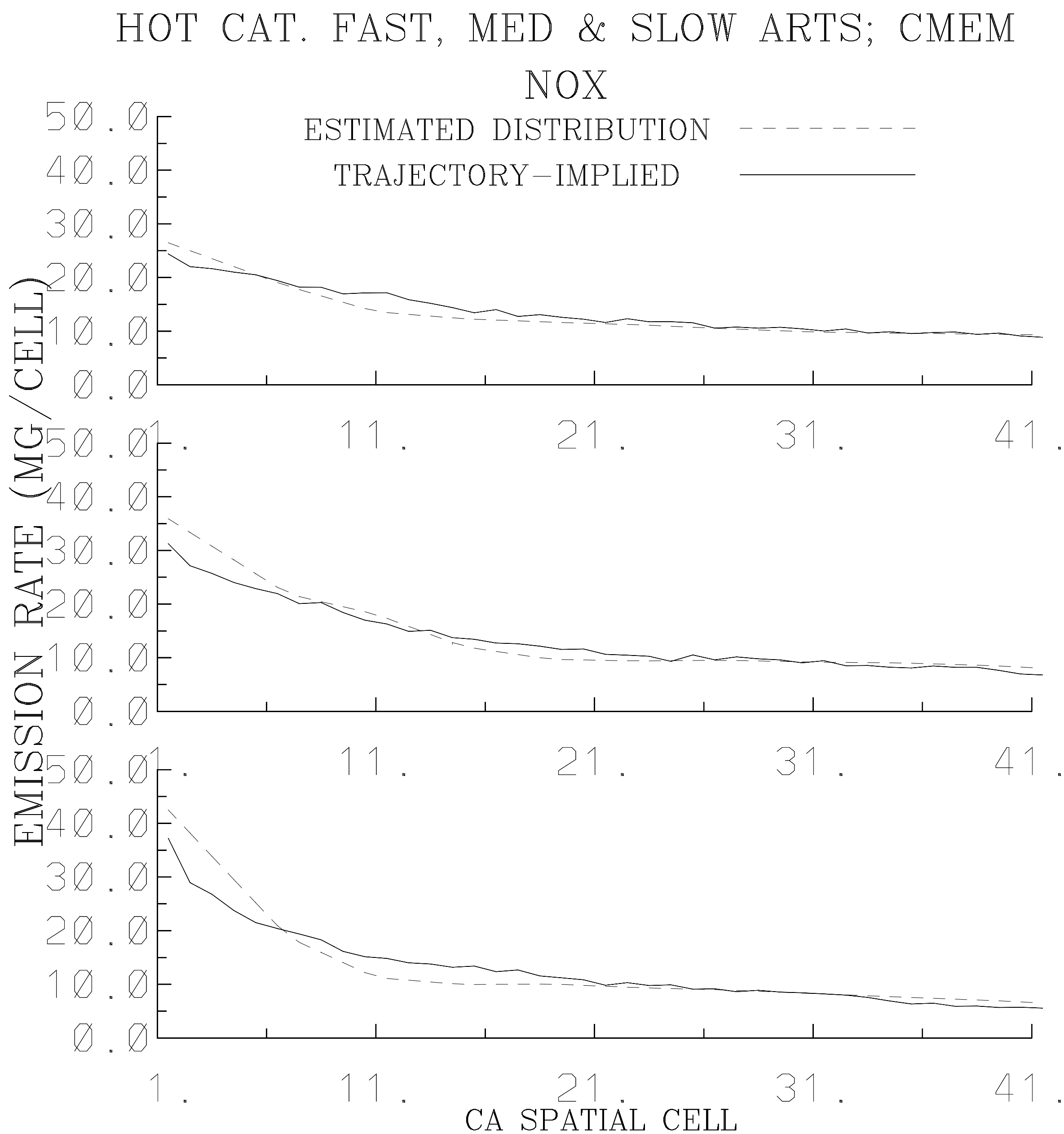

Figure 8. Comparison of estimated and trajectory-implied NOx emissions for a fast arterial (top), a medium arterial (middle), and a slow arterial (bottom).

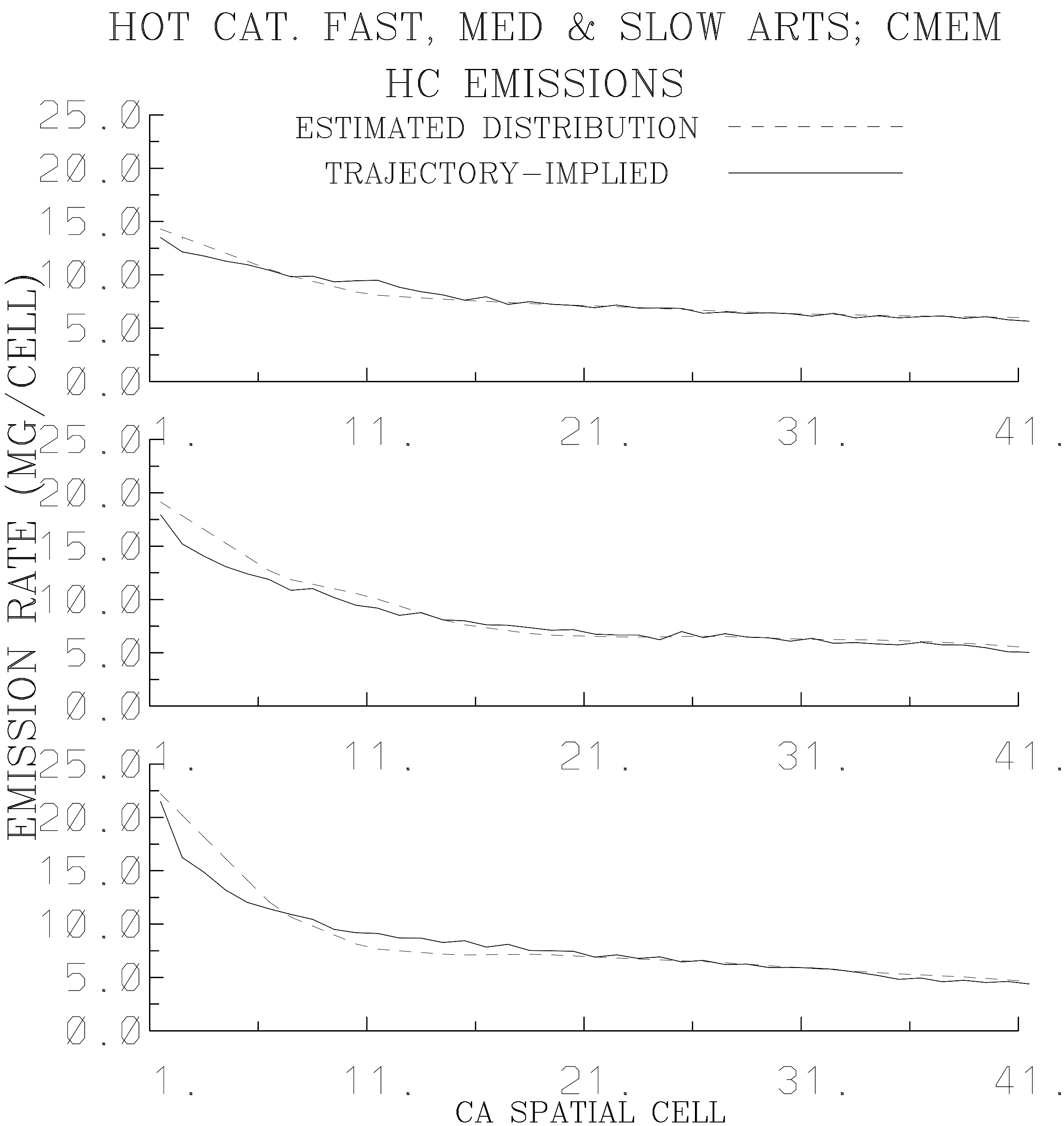

Figure 9. Comparison of estimated and trajectory-implied hydrocarbon emissions for a fast arterial (top), a medium arterial (middle), and a slow arterial (bottom).

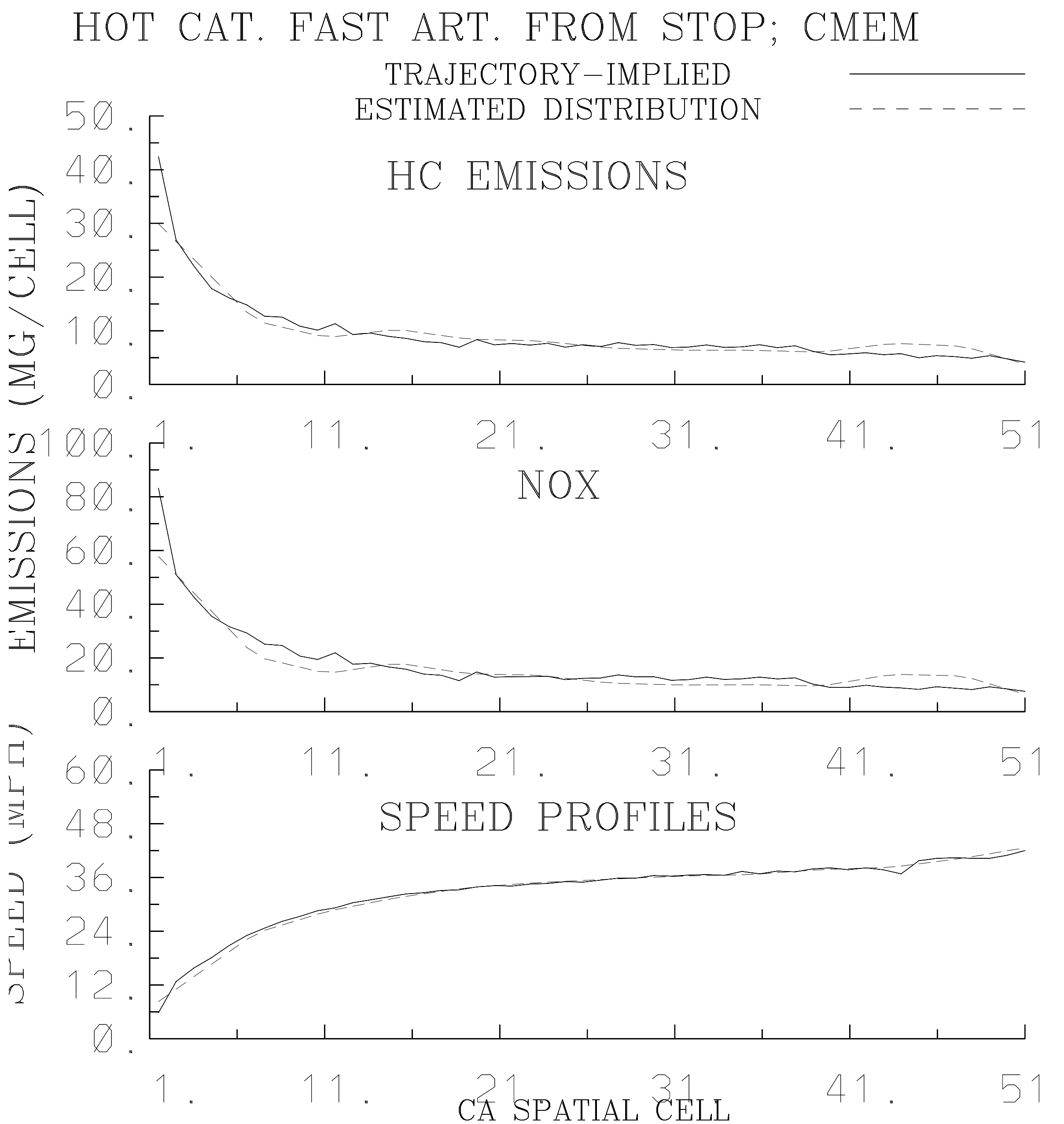

Figure 10. Comparisons of estimated and trajectory-implied speeds (bottom), NOx emissions (middle), and hydrocarbon emissions (top) for fast-arterial vehicles accelerating from slow speeds at a signal.